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AEROSPACE INFORMATION REPORT

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HEAT TRANSFER PROBLEMS ASSOCIATED
WITH AEROSPACE VEHICLES

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1. PREFACE: This document is prepared as a part of the specific assignment to SAE Subcommittee A-9C of the task entitled "Heat Transfer Problems Associated with Aerospace Vehicles". This broad assignment will be handled in three phases as follows:

1. To outline major heat transfer problems which apply to aerospace vehicles.
2. To indicate improvements required in the technology of heat transfer, and the long range objective for future effort.
3. To outline the best methods and techniques presently available for solving the above problems.

The intention of this Information Report is to provide an initial approach to the first of the above objectives. It is intended that this document will be amplified in subsequent issues to more fully treat the complete problems of heat transfer related to aerospace vehicles and the equipment they contain.

2. PURPOSE: This compilation reflects inputs from a varied cross-section of aerospace industries. In view of the above, the report is intended to serve as a listing of aerospace industry problem areas in the field of heat transfer. These are the problem areas where improved analytical and experimental investigations and techniques are required if aerospace designers are to design and produce vehicles of high performance and reliability. Thus, the document should be useful as a guideline for present and future industrial, governmental and educational study programs.
- 2.1 General: As in any instance where problem areas are listed in a particular discipline or task, the listing must be compatible with the state-of-the-art at the time of its compilation. The discipline of heat transfer is no exception. In fact, this particular discipline has experienced a more than average growth in the last decade. Where heat transfer was once a minor or even negligible input in the overall system design, it has now become one of the prime considerations. This basic need has given rise to numerous experimental and analytical studies in this field.

The results of these experimental and analytical studies can well outdate any listing of this type in a comparatively short time. Thus, with this in mind, discretion should be exercised in the use of the contents of this report.

3. SCOPE:

- 3.1 Heat Transfer Mechanism: The discipline of heat transfer concerns itself basically with the three modes of transferring thermal energy (convection, conduction, and radiation) and their inter-relations. In any phase of aerospace vehicle design, the importance of any of these basic modes will vary depending upon the natural and induced environment the mission imposes as well as the vehicle configuration.

- 3.2 Vehicle Mission Phases: The vehicle mission conditions or phases considered in this compilation encompass the following:

- Storage
- Pre-flight or standby
- Atmospheric flight
- Earth orbit
- Interplanetary space travel
- Earth re-entry
- Planet re-entry
- Landing and post landing period

- 3.3 Vehicle Configuration: The vehicle configuration is that which is required to achieve manned and unmanned conditions as outlined above.

- 3.4 Environment:

- 3.4.1 Natural: Consideration in this area is limited to the pressure, temperature, density and composition variations of the media wherein the vehicle operates.

- 3.4.2 Induced: This area encompasses that environment which has been induced because of vehicle configuration and mission. This section is concerned with factors such as the thermodynamic and transport properties of the media surrounding the vehicle (equilibrium vs. non-equilibrium).

4. INTRODUCTION:

This resume of problems is divided into two principal areas:

- 1. Internal
- 2. External

This division of two principal areas is an artifice to facilitate clarity of presentation since internal thermal design of a vehicle is strongly dependent upon external environmental conditions. Complete separation of heat transfer problems into "external" and "internal" types is difficult, if not impossible in some vehicles.

The external problems are those which occur when one attempts to assess the effects of the free stream and space at the vehicle external surface. On the other hand, the internal problems are those which begin on the external surface of the vehicle. The areas considered herein include structure, components, life support, propulsion and auxiliary power.

5. INTERNAL HEAT TRANSFER PROBLEMS: Internal thermal design requires the consideration of all phases of vehicle mission conditions, i.e., storage, pre-flight, standby, flight in the atmosphere, earth orbiting, interplanetary flight, terminal trajectory phase, landing and post landing period. The heat transfer problems which need to be solved to produce vehicles of improved quality and performance are presented in four classifications. These classifications are: (1) design requirements, (2) materials, (3) methods of analysis, and (4) experimental techniques.

Often, satisfactory techniques are available to control the temperature of a component or device, provided the allowable temperature and thermal output limits for the critical part are specified. These allowable limits, which are the design requirements, must be known to satisfactorily design the passive or active method needed to control the component within the desired range of temperatures.

Materials used in vehicle structure and components constitute significant conductive paths which influence the temperature of the vehicle interior. In space systems, a significant portion of the heat transfer occurs by radiation which is influenced by the optical properties of the interior surfaces of the vehicle and the component surfaces.

The problems listed in the analytical methods category are those where an understanding of the heat transfer mechanism is incomplete or a satisfactory analytical model is nonexistent. Solutions to many of these problems will require both analytical and experimental effort.

Problems listed in the experimental category concern the employment of experimental techniques to obtain design data or the simulation of conditions that are needed to verify the efficiency of a particular temperature control technique or system.

5.1 Design Requirements:

- 5.1.1 Critical Component Temperature and Pressure Limitations: Satisfactory thermal design of aerospace vehicles depends on a complete definition of the allowable storage and operating temperature limits of all components and mechanisms which are part of the vehicle. Under standard atmospheric conditions, the heat generated within equipment can generally be dissipated at a temperature which is not detrimental to the equipment. Under conditions to be encountered on satellites and re-entry vehicles, these favorable conditions may not exist. Consequently, attention to the mechanism of heat transfer from components to their surroundings, is required to obtain a satisfactory installation.

The following information is needed:

- (1) The maximum and minimum allowable temperature of the equipment under continuous and intermittent duty.
- (2) The maximum and minimum allowable temperature under transient conditions.
- (3) Maximum and minimum storage temperature of the equipment.
- (4) Component hot spot temperature vs. mean time to failure.
- (5) Intermittent and continuous heat rejection rates of the equipment (as a function of part temperature).
- (6) Location of the above maximum and minimum temperature within the equipment.

- (7) Type of heat sink employed in equipment package.
- (8) Minimum allowable pressure.
- (9) Type of component enclosure seal.
- (10) Primary mode of heat transfer utilized in transferring heat from the components to the equipment enclosure.
- (11) Reliability and length of operation as a function of part temperature.

It is imperative to clearly define the environment in which data on temperature limitations are obtained. A considerable amount of component performance data is presently inadequate for space vehicle designs. For example, temperature data obtained for equipment sitting on a work bench with unknown convective characteristics may contribute little, if any, information toward the design of a space vehicle.

- 5.1.2 Regulation, Sensing, and Control of Environmental Systems: Available and proposed systems are inadequate for long space flights. They are too heavy, too complex, too costly, consume too much power, are too difficult to repair in flight, and require a large inventory of spares for long flights because of a lack of component interchangeability.

A program should be initiated to develop systems with components that are interchangeable; systems that are passively operated, thus consume no power; are simple, rugged, reliable, maintenance free, and do not require elaborate manufacturing techniques; that in no way depend on gravity forces; and that incorporate wherever possible a manual operational mode.

- 5.1.3 Equipment Environmental Control:

- 5.1.3.1 Techniques are required for overcoming rapid electronic and electro-mechanical component structural mass temperature change influences on functional performance. This includes transition from nonoperational soak temperatures to the functional operating range and rapid transition occurring during functional operation. Examples:

- (1) Changing inertial guidance platform mass temperature from either a low or high temperature soak condition to stabilized operational temperature in shortest possible countdown period (this generally exceeds allowable drift rate on gyros).
- (2) Subjection of operating electronic components to transient high ambient air temperatures during vehicle flights.
- (3) Holding an inertial platform at constant temperature during transition from static to operation flight conditions.

Techniques required to solve the problems mentioned above are being developed in the course of designing systems with rapid temperature changes.

- 5.1.3.2 Techniques for achieving a minimum response time in conditioning control system reaction. This requirement exists particularly in ground support conditioning equipment as it responds to satisfy vehicle component needs prior to launch.
- 5.1.3.3 Development of electronic and associated mechanical components more resistant to rate of temperature changes.
- 5.1.3.4 Development of non-magnetic module surfaces that retain or dissipate heat better than those presently available. Development of surfaces might be directed as follows:
 - (1) Improved surface geometry (shape, roughness, etc.)
 - (2) Improved surface radiating characteristics, etc.
 - (3) Improved module materials.
 - (4) Improved packaging techniques.
- 5.1.3.5 Development of improved techniques and concepts (which are simple, reliable, and compact) for equipment environmental control. This would encompass investigations of free and forced cooling with different media as well as phase change and energy conversion (Peltier, etc.) techniques.
- 5.1.3.6 The thermal packaging of electronics to effectively utilize cold plate cooling techniques.
- 5.1.3.7 The practical design of small heat pumps for sensitive equipment
 - (1) thermoelectric pumps for crystal oscillators, stable platforms, urine stills, etc.
 - (2) closed cycle heat pumps for long time I.R. sensors.
- 5.1.3.8 The development of dielectric potting compounds for electronics with higher thermal conductivities so as to facilitate heat transfer.
- 5.1.3.9 The design of active-passive cooling packages for short flight time operating equipment so that the active mode is used during long duration ground checkout and the passive mode (waxes, etc.) during short time boost.
- 5.1.3.10 Refrigeration systems for reliquifying cryogenic boiloff during long time space operations.
- 5.1.3.11 Reliable positive expulsion venting techniques for cryogenics during zero "g" operation so as to avoid the complexity and penalties associated with supercritical storage.
- 5.1.3.12 Efficient, reliable methods other than by the use of gases to transfer environmental heat to cryogenic heat sinks.
- 5.1.3.13 Development of "guide posts" which could be utilized by the designer as a check list to be followed in the design of cooling systems for highly critical electronic gear.